MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DEPARTMENT OF METEOROLOGY
CAMBRIDGE 39, MASSACHUSETTS

TECHNICAL REPORT NO. 14

RESEARCH ON ATMOSPHERIC PRESSURE CHANGES

Contract N5ori-07804
Office of Naval Research
United States Navy Department

NOVEMBER 15, 1953

OFFICE OF NAVAL RESEARCH

United States Navy Department

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SEA-LEVEL PRESSURE PATTERNS ASSOCIATED WITH 500-MB CONTOUR PATTERNS

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November 15, 1953

ABSTRACT

The association between sea-level and 500-mb patterns is obtained by analyzing the hydrostatic contribution of 500-mb height changes to pressure changes at sea level. The 500-mb height changes are also utilized to analyze the changing divergence fields in the upper troposphere. From this dual analysis of 500-mb changes criteria are established for development of new surface systems and deepening or filling of existing surface systems. The forecast aids are supported by various empirical studies and are illustrated by three synoptic situations.

SEA-LEVEL PRESSURE PATTERNS ASSOCIATED WITH

500-MB CONTOUR PATTERNS

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INTRODUCTION

During the past decade many techniques have been suggested for the use of upper-air data in the construction of prognostic charts at sea level. Recently Riehl and collaborators (1) have presented an extensive analysis of the relationship between the surface prognosis and various features of the upper-air pattern together with an extensive bibliography of pertinent literature. It is evident that the 500-mb chart has evolved as a basic synoptic tool for the forecaster. It is pertinent, therefore, to discuss the surface prognostic chart in the light of the interrelationships between surface and 500-mb charts. This paper presents some of these interrelationships and their forecast significance for sea-level charts. Many of the prognostic aids are similar to those discussed by Riehl. The principal difference resides in the method of analysis. Here the prognostic tools are related to a single upper-air chart and the height changes which are commonly drawn on the chart.

SURFACE AND 500-MB CHANGES

The problem of the prediction of cyclonic and anticyclonic systems can be considered as one of estimating the field of pressure change. Attention is focused first, therefore, upon the types of surface pressure changes associated with 500-mb changes. It is convenient to consider three parameters:

Δp_o the sea-level pressure change,

ΔH_{500} the 500-mb height change, and

ΔT the change in mean temperature between p_o and 500 mb.

From the hydrostatic equation it follows that

$$\Delta p_o = p_o \frac{g}{RT} (\Delta H_{500} - H \Delta T/T) \qquad (1)$$

where H is the height of the 500-mb surface, T the mean temperature between p_o and 500 mb, g the acceleration of gravity and R is the gas constant. This formula shows that when ΔT is zero, Δp_o is of the same sign as ΔH_{500} and that its magnitude is closely approximated by considering that a 100-ft change at 500 mb is equal to a 4-mb change at sea level. It follows from the equation that the sign and magnitude of ΔT is the prime factor which contributes to a variety of Δp_o's with a single ΔH_{500}, as demonstrated in table 1. An analysis of 1762 cases of 12-hr changes over North America, during the winters of 1951 and 1952, demonstrated the lack of correspondence between the sign and magnitude of Δp_c and ΔH_{500}. These data gave a correlation coefficient of +0.25 between ΔH_{500} and Δp_o. It is evident, then, that height changes at 500 mb cannot be used to determine sea-level changes without considering the change in mean temperature below 500 mb.

A change in the temperature (ΔT) of the column below 500 mb arises from the combined effects of horizontal advection, adiabatic temperature change and non-adiabatic effects near the earth's surface. Many empirical studies have shown that the first two factors tend to act in such a manner that warm-air advection is accompanied by adiabatic cooling and cold-air advection by adiabatic warming. A good correlation should be expected, therefore, between the advection below 500 mb and ΔT. Data

during February 1952 gave a correlation of -0.68 between the integrated advection below 500 mb (warm advection considered negative) and ΔT. It is apparent that the most important factor which contributes to values of ΔT in equation (1) is the horizontal advection. The advection and ΔT can be large in regions of strong temperature contrast below 500 mb and must be small in regions of weak thermal gradient. It should follow that in regions of weak thermal gradient, there is a positive correlation between ΔH_{500} and Δp_o. This conclusion is supported by a study of changes during the winter of 1951-1952. 185 cases of 12-hr changes at two west coast stations (index numbers 398 and 798) gave a correlation coefficient of +0.67 between Δp_o and ΔH_{500}. These stations were located in regions of weak gradients of temperature so that ΔT was usually small. Such studies of ΔH_{500}, ΔT and Δp_o clearly demonstrate the necessity of the separate consideration of ΔH_{500} and ΔT for the determination of the sign and magnitude of Δp_o.

INTENSIFICATION OF SURFACE PRESSURE SYSTEMS

Surface pressure systems are associated with characteristic fields of horizontal divergence and vertical motion. An important aspect of the intensification of these systems is the contemporary change in the intensity of the horizontal divergence. Hence the 500-mb height changes will be analyzed not only as contributions to Δp_o, as in equation (1), but also as indicators of a changing divergence field. It is convenient to refer 500-mb changes to trough-ridge patterns and consequently the behavior of pressure systems at sea level will be classified according to their location relative to the 500-mb chart.

(a) Development of new pressure systems. The development of a new cyclone requires the presence of a new area of pressure fall. Equation (1) states that such a region of $\Delta p_0 < 0$ arises simultaneously with occurrence of $\Delta H_{500} < 0$ or with $\Delta T > 0$. It appears that significant values of ΔT are usually associated with horizontal advection as judged by the geostrophic flow. Synoptic charts indicate that new prominent regions of warm advection are found after the cyclone is once developed and that the origin of the initial fall for the cyclone cannot be attributed to advection. It is evident, then, that the initial surface cyclogenesis generally accompanies the appearance of a region of height fall at 500 mb. A favored location is beneath and ahead of an intensifying trough at 500 mb. This type of trough intensification at 500 mb has been discussed by the author (2) in connection with the downstream progression of intensification. It should be distinguished from the trough development at 500 mb which accompanies the deepening of an established cyclone, as discussed below in section (b).

It is difficult to obtain observational data at the initial stage of cyclone development in view of the 12-hr time gap between successive radiosonde observations. An attempt has been made to analyze the initial changes by selecting radiosonde stations immediately in advance of the position of a cyclone twelve hours after it was first detected. The cyclone tracks in the Monthly Weather Review were used to determine the locations of the cyclone. A study of 122 new cyclones showed that, in the mean, a surface fall of 4.8 mb was accompanied by a height fall of 103 ft at 500 mb. This empirical study of cyclones over the central and eastern part of North America substantiates the argument

that the initial sea-level fall is beneath height falls at 500 mb and that there is slight temperature change below the 500-mb surface.

(b) Intensifying pressure systems. If an existing cyclone is to deepen it must be associated with intensifying pressure falls. From equation (1) it follows that large pressure falls occur where ΔH_{500} is negative and where ΔT is positive. Large negative values of ΔH_{500} are found ahead of intense migratory troughs and within deepening troughs at 500 mb. ΔT is large in regions of strong warm air advection. Hence the ideal location for a deepening surface cyclone is ahead of an intensifying 500-mb trough and imbedded in a zone of strong temperature contrast below the 500-mb surface. The deepening of the surface cyclone is accompanied by height changes and trough - ridge development of short wavelength at 500 mb. The 500-mb falls which accompany the surface deepening should be distinguished from those height falls, within and ahead of a major trough at 500 mb, which initiate the surface development. This dual aspect of cyclone development is discussed by Bjerknes (3) in terms of "unstable frontal wave action" and "unstable growth of an upper wave trough". The vertical stability and relative humidity are modifying factors. In the case of moist unstable air, vertical motion does not detract from the advective warming and, consequently, the deepening is enhanced.

It will now be shown that such a situation meets the criterion of Riehl and collaborators. They state that, "The surface pressure falls where the relative vorticity decreases downstream in the upper troposphere." This rule arises from the consideration that

pressure falls are accompanied by horizontal divergence in the upper troposphere and that horizontal divergence ($div_2 \mathbb{V}$) is found where the relative vorticity (ζ) of individual parcels decreases with time, that is

$$\frac{1}{f+\zeta} \frac{d}{dt} (f + \zeta) = - div_2 \mathbb{V} \qquad (2)$$

where f is the coriolis parameter. The individual vorticity change may be expressed as

$$\frac{d}{dt} (f + \zeta) = \frac{\partial \zeta}{\partial t} + V_s \frac{\partial \zeta}{\partial s} \qquad (3)$$

where the s-axis is along a streamline. Equation (3) presumes that attention is focused on prominent changes in ζ so that $\frac{df}{dt}$ and $w\frac{\partial \zeta}{\partial z}$ can be neglected. From this analysis it is evident that intensifying pressure falls at sea level require increasingly negative values of $\frac{\partial \zeta}{\partial t}$ and $V_s \frac{\partial \zeta}{\partial s}$ in the upper troposphere. The height change pattern in figure 1 shows the change in the contour field, and, therefore, the change in the relative vorticity to the extent that the actual vorticity is given by the vorticity of the geostrophic wind. The relative cyclonic vorticity is increasing with time about the center of ΔH_{500} and $V_s \frac{\partial}{\partial s}$ is becoming more negative about M. There is a high correlation between 500-mb changes and changes in the upper troposphere and lower stratosphere. A correlation coefficient of +0.85 was obtained for 384 parts of 500- and 300-mb changes from widely distributed stations. It is apparent that the isallobaric pattern at 300 mb is similar to the one at 500 mb. V_s in the upper troposphere depends primarily upon the mean thermal gradient with large values of V_s above a region of strong tropospheric temperature contrast. Hence when a surface cyclone is located in a zone of

strong temperature contrast ahead of an intensifying 500-mb trough (M in figure 1), $V_s \frac{\partial \mathcal{S}}{\partial s}$ is becoming increasingly negative. The upper divergence is increasing, consistent with the postulated intensifying pressure falls at sea level.

A similar analysis of pressure rises indicates that an anticyclone ahead of a building ridge at 500 mb is favorably located for anticyclogenesis. Here $\Delta H_{500} > 0$ and ΔT with cold air advection is negative. $\frac{\partial \mathcal{S}}{\partial s}$ is increasing downstream from the center of height rises at 500 mb so that $V_s \frac{\partial \mathcal{S}}{\partial s}$ and the high-level convergence are becoming larger--a satisfactory condition for anticyclogenesis.

(c) Minor or weakening pressure systems. Weak isallobaric fields are associated either with minor pressure systems or with the filling of cyclones and the weakening of anticyclones. The situations favorable for such isallobaric fields are more or less the converse of those discussed in the preceding section. Three general types of situations are associated with small pressure changes at sea level. (1) A weak air-mass contract in the troposphere means that low-level advection can contribute little to the pressure change. (2) There are many occasions when ΔH_{500} and ΔT have the same sign. In these circumstances Δp_o is not large. A cyclone is likely to fill when it is centered between AF in figure 2 because the ΔH_{500} is usually positive and thereby reduces the magnitude of the surface falls. Similarly, an anticyclone located ahead of a 500-mb trough is likely to weaken. (3) The weakening of sea-level pressure systems may arise from a change in the magnitude of ΔH_{500}. A surface cyclone located ahead of a weakening trough at 500 mb fills when the diminished value of ΔH_{500} is not

offset by intensified advection and a larger ΔT below 500 mb. Likewise anticyclones ahead of weakening ridges at 500 mb should decrease in intensity.

Weakening pressure systems at sea level are accompanied by diminishing divergence fields in the upper troposphere. As in the previous section the changing divergence fields may be deduced from the vorticity equation. The 500-mb isallobaric fields show the changes in ζ in the upper troposphere and V_s decreases with a weakening of the air mass contrast below 500 mb.

(d) <u>Non-adiabatic influences.</u> The ΔT in equation (1) can arise from the non-adiabatic addition of heat. The most favorable circumstance for a large ΔT occurs with the flow of cold continental air over warm water. The quantitative importance of this process is yet to be analyzed. However, the marked tendency for surface cyclones to deepen off the east coasts of continents suggests that this process is important. In this respect it should also be noted that two other favorable factors also prevail with such cyclones, namely, strong thermal contrast and moist unstable air.

(e) <u>Empirical evidence on surface systems.</u> A study of the day-to-day behavior of pressure systems during February - April 1951 has provided empirical information on changes in cyclonic activity. The data are restricted to the behavior of katallobaric systems rather than to the changes in central pressure of cyclones. The frequent asymmetry of the pressure field around a new cyclone can give rise to an erratic behavior of the center of the cyclone whereas the katallobaric center may move and change in a regular fashion. On occasions the new

development of a cyclone is first indicated by falling pressure within an anticyclone, such as may occur over the Rocky Mountain plateau. Here the cyclogenetic process is first detected in the field of pressure change. Of course once a cyclone is well established an intensifying katallobaric system is accompanied by a deepening of the cyclone.

The data in this study were confined to katallobaric systems over North America, whose central value at some stage exceeded a change of 10 mb/12 hr. The average picture of the most prominent cases of intensifying and weakening katallobaric areas is presented in Table 2. 28 out of 29 cases of intensification were located between B and C (figure 2) with the mean location about midway between the trough (B) and ridge (C) at 500 mb. 15 of the 21 pronounced weakening cases were located at A or between A and B. The remaining 5 cases of pronounced weakening were located between B and C. For Table 2, intensification was defined as 50 per cent or more increase in the central pressure change of the katallobaric center during a 12-hr period. Weakening was defined as a 33 1/3 per cent or more decrease in the central pressure change. Table 3 gives a classification of all katallobaric systems. These data show the same general features of Table 2 in that both ΔH_{500} and ΔT contribute to the intensification and weakening, respectively. It is important to note from Table 3 that 60 per cent of the weakening cases occur between B and C while only 20 per cent of the intensifying cases are located between A and B. A further subdivision of the data in the B to C region is presented in Table 4. The group of 23 intensifying cases represents situations where the initial fall arose primarily from large falls at 500 mb while the fall for the

28 cases of intensification was accompanied by strong warming below 500 mb. Likewise the weakening cases are divided into low- and high-level contributions respectively.

These empirical data support the following criteria for the deepening and filling of cyclones:

(1) Surface cyclones which deepen rapidly are located ahead of a 500-mb trough. The simultaneous development of the 500-mb trough and the location of the cyclone in a zone of strong air-mass contrast below 500 mb ensure the deepening of the cyclone.

(2) Surface cyclones located on or ahead of a 500-mb ridge have a definite tendency to weaken. The most prominent cases of weakening are located in this region. The small percentage of intensifying cyclones do not change markedly.

(3) A cyclone ahead of a 500-mb trough with surface falls directly beneath 500-mb falls, intensifies when it becomes located in a region of strong low-level temperature contrast. Frequently new cyclones develop in this manner.

(4) Many cyclones located ahead of a 500-mb trough do not intensify. A cyclone which moves to a region of weak air-mass contrast fills with the weakening low-level advection. The surface filling may also arise from a decrease in the contribution of the 500-mb falls to the surface falls. This latter situation prevails either with the weakening of the 500-mb trough or with the relative migration of the surface cyclone toward the 500-mb ridge.

The forecast aids stress the necessity for the separate consideration of the air-mass contrast and the deepening and filling of the major troughs at 500 mb.

Bodurtha (4) has decribed in detail some prominent cases of anticyclogenesis. The anticyclones intensify prominently when they are located beneath and ahead of an intensifying ridge at 500 mb.

MOTION OF SURFACE PRESSURE SYSTEMS

As in the case of the discussion of intensification, the analyses of the motion of cyclones and anticyclones will be based upon the motion of pressure-change centers. Consequently the following comments assume that the pressure system moves in the same direction and with the same speed as the isallobaric system. With vast anticyclones and strongly asymetrical cyclones care must be taken to recognize that the center of the pressure system may not follow the isallobaric center.

Surface cyclones may be classified into two broad categories. (1) A "cold" cyclone is accompanied by surface falls directly beneath 500-mb falls (Δp_o and ΔH_{500} have same sign and $\Delta T \rightarrow 0$). Such cyclones move in a direction and with the speed of the 500-mb height falls. The prediction of the motion of the surface cyclone is based upon the motion of the 500-mb trough located above the surface cyclone. A previous study (2) shows that such "cold" cyclones move slowly--an average speed of about 24 mph across North America. (2) The pressure falls with a "shallow" cyclone are associated with temperature rises between 1000 mb and 500 mb and no height falls at 500 mb (Δp_o -, ΔT + and $\Delta H_{500} \rightarrow 0$). Since the temperature rises occur primarily with

warm-air advection the cyclone moves parallel to the mean isotherms between sea level and 500 mb. The forecaster must consider the change in the orientation of the isotherms during the forecast period on account of the varying wind flow perpendicular to the isotherms. Hence the cyclone moves in a direction somewhere between the direction of the isotherms through the cyclone center and the sea-level geostrophic flow ahead of the cyclone. The 500-mb flow conveniently combines these two components and such "shallow" cyclones move parallel to the 500-mb flow directly above and immediately ahead of the surface system. The speed is dependent upon the spacing of the mean isotherms so that cyclones move rapidly when the temperature gradient is strong. Since the speed of the 500-mb flow is greatly influenced by the thermal wind below 500 mb it follows that there is a direct relationship between the speed of the cyclone and the geostrophic wind at 500 mb. These statements on direction and speed of this class of cyclone appear to be in reasonable agreement with Riehl's comments on the validity of the steering principle.

Practically all surface cyclones show some "cold" and "shallow" characteristics and the forecaster must weigh the relative importance of the dual features. For example, a cyclone whose pressure falls arise primarily from low-level temperature rises moves more nearly in accord with the steering principle than with the 500-mb trough. Since the forecast of intensification involves a prediction of the change in the major troughs at 500 mb it is evident that the prediction of motion is dependent upon the prediction of intensification. If a major trough at 500 mb, to the rear of a surface cyclone, is predicted to intensify markedly, it follows that the high-level contribution to the surface

falls is increasing and therefore, the motion of such a cyclone is being controlled to an increasing extent by the motion of the 500-mb falls. Many deepening cyclones which slow down belong to this category. On the other hand a cyclone which deepens because it is embedded in a strong zone of temperature contrast below 500 mb moves in accordance with the steering principle. These deepening cyclones may accelerate. The fact that surface cyclones often change in character during a 24-hr period complicates the estimation of the direction and speed of the cyclone. Nevertheless, once the forecast of intensification has been made the prediction of the motion can be based upon the foregoing rules for "cold" and "shallow" cyclones.

The motion of anticyclones may be analyzed in a like manner. The shallow anticyclones move in accord with the steering principle while deep anticyclones ahead of a 500-mb ridge move slowly with the 500-mb ridge.

SYNOPTIC PROCEDURE AND EXAMPLES

In this paper the author has attempted to demonstrate how the 500-mb pattern and its height changes may be used to aid the prediction of intensification and motion of surface systems. The basic forecast tools are

(1) A 500-mb chart with 12-hr height changes.

(2) A surface map with the mean isotherms between 1000 mb and 500 mb.

(3) A map of 12-hr pressure changes at sea level.

The sets of 12-hr changes facilitate the analysis of the past development. For example, the presence of 500-mb changes almost directly above

like surface changes, means little contribution to the surface change from the layer below 500 mb. The surface system is moving and changing intensity in accord with the 500-mb changes. On the other hand, a surface change pattern beneath zero or unlike changes at 500 mb shows that the surface system is moving and changing intensity according to the contributions between the surface and 500 mb. The mean isotherms show the possibilities for low-level contributions to the sea-level change. Also when the isotherms are drawn on the surface map, the advection fields stand out very clearly. The disadvantage of drawing the mean isotherms on the 500-mb chart is the marked tendency of the 500-mb contours to parallel the isotherms thereby increasing the possibility of erroneous depiction of advection areas. Finally, the 500-mb changes indicate the changing vorticity field in the upper troposphere so that they may be used to investigate the changing divergence fields. A set of surface developments are included as illustrations of the principles raised in the foregoing sections.

(a) <u>Case of February 26th - 27th, 1953.</u> This situation illustrates a variety of surface developments. On the 26th there is a deep low north of the Great Lakes which is accompanied by surface falls almost directly below 500-mb falls. The lack of an isotherm concentration across the low center accounts for unimportant low-level contributions to the pressure changes. This "cold" low moved slowly (22 mph) and changed little in intensity. In contrast a new low was developing near Washington, D. C. ahead of the 500-mb trough and imbedded in a strong zone of temperature contrast. This low moved faster (40 mph) and deepened rapidly. Since the major contribution

to the pressure falls came from temperature rises below 500 mb the low moved approximately parallel to the 500-mb flow. The northward component to the motion during the second half of the period was in reasonable agreement with the 500-mb direction at that time. In this instance the high humidity and instability of the warm air was a favorable additional factor for rapid deepening. The small katallobaric area in southern Alberta was another low-level system imbedded in a zone of strong temperature contrast. It followed the steering principle and moved very rapidly (57 mph). The lack of intensification was consistent with a location to the west of the 500-mb trough so that during the 26th there were no height falls at 500 mb over the surface falls.

(b) Case of March 3 - 4, 1953. The asymetrical low in Texas had changed little during the 24-hr period prior to 0630 GMT on March 3rd. However, the synoptic situation had all the ingredients for a rapidly deepening cyclone. There was a strong zone of temperature contrast ahead of a deep 500-mb trough and the warm air was moist and unstable. The deepening commenced when the 500-mb trough and its height falls moved eastward so that the height falls contributed to sea-level falls in a region of strong temperature contrast. From March 3rd to 4th the cyclone deepened and moved rapidly. Since the pressure changes were associated primarily with prominent temperature changes below 500 mb the cyclone followed the steering principle. By March 4th there was a prominent short wavelength trough and ridge at 500 mb above the surface cyclone. This change in the pattern at 500 mb is part of the deepening process. Such 500-mb changes are common

with deepening cyclones imbedded in a zone of strong temperature contrast below 500 mb.

(c) <u>Case of March 26 - 27, 1953.</u> From the 25th to the 31st of March there was an unusual period of slow-moving cyclonic activity along the mid-Atlantic Coast. Ordinarily cyclones develop and move rapidly when they are located in the zone of strong temperature contrast commonly present along the Atlantic Coast. The maps for 0630 GMT March 26th show an unusual pattern. The thickness lines, through and ahead of the cyclone center, demonstrate that the thermal contrast is weak. Consequently, the surface pressure falls are beneath 500-mb falls and the cyclone is moving with the slowly-changing cold low at 500 mb. Minor cyclone waves developed and moved northward into the primary low. These weak disturbances were imbedded in the stronger thermal contrast to the south of the main center. This anomalous pattern for the mid-Atlantic Coast demonstrates that a zone of strong thermal contrast across the cyclone is a necessary requirement for rapidly moving cyclones.

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3. Bjerknes, J., 1951: Extratropical cyclones, Compendium of Meteorology, p. 577.

4. Bodurtha, F. T., 1952: An investigation of anticyclogenesis in Alaska, Journal of Meteorology, Vol. 9, p. 118.

Table 1. Surface pressure changes (Δp_o in mb) related to 500-mb height changes (ΔH_{500}) and changes in mean temperature (ΔT) between 500 mb and p_o. Table constructed for p_o = 1010 mb, H (height of the 500-mb surface) = 17850 ft and T = 265 K.

ΔH_{500} in ft. / ΔT in °C	-400	-200	0	+200	+400
+6	-32	-24	-16	-8	0
+3	-24	-16	-8	0	+8
0	-16	-8	0	+8	+16
-3	-8	0	+8	+16	+24
-6	0	+8	+16	+24	+32

Table 2. Analysis of rapidly intensifying and weakening katallobaric systems on sea-level charts. All pressure changes in mb per 12 hr. The "12-hr change" gives the increase or decrease in the central value of the katallobaric system.

Type	Intensifying	Weakening
No. of cases	29	21
Initial value	-9.0	-15.7
12-hr change	-6.9	+ 7.6
1000 -500 contribution	-2.6	+ 3.7
500-0 contribution	-4.3	+ 3.8

Table 3. Analysis of the behavior of 12-hr katallobaric centers at sea level. The A, B and C refer to the letters on Fig. 2.

Location	Between A and B		Between B and C	
Type	Intensifying	Weakening	Intensifying	Weakening
No. of cases	14	21	51	35
Initial value	-11.1	-14.7	-10.3	-15.5
12-hr change	- 3.0	+ 5.0	- 5.2	+ 4.8
1000-500 contribution	- 2.3	+ 3.4	- 2.0	+ 2.8
500-0 contribution	- 0.8	+ 1.6	- 3.2	+ 2.0

Table 4. Subdivision of 12-hr katallobaric centers at sea level, located between B and C, into low- and high-level contributions.

Type	Intensifying		Weakening	
No. of cases	23	28	16	19
Initial p_o	-9.7	-10.6	-14.6	-16.3
Initial 1000-500	-1.8	- 9.8	- 2.0	-15.0
Initial 500-0	-7.9	- 0.8	-12.6	- 1.3
12-hr change	-5.4	- 5.1	+ 4.1	+ 5.3
1000-500 contribution	-5.7	+ 1.0	- 0.2	+ 5.4
500-0 contribution	+0.3	- 6.1	+ 4.3	- 0.1

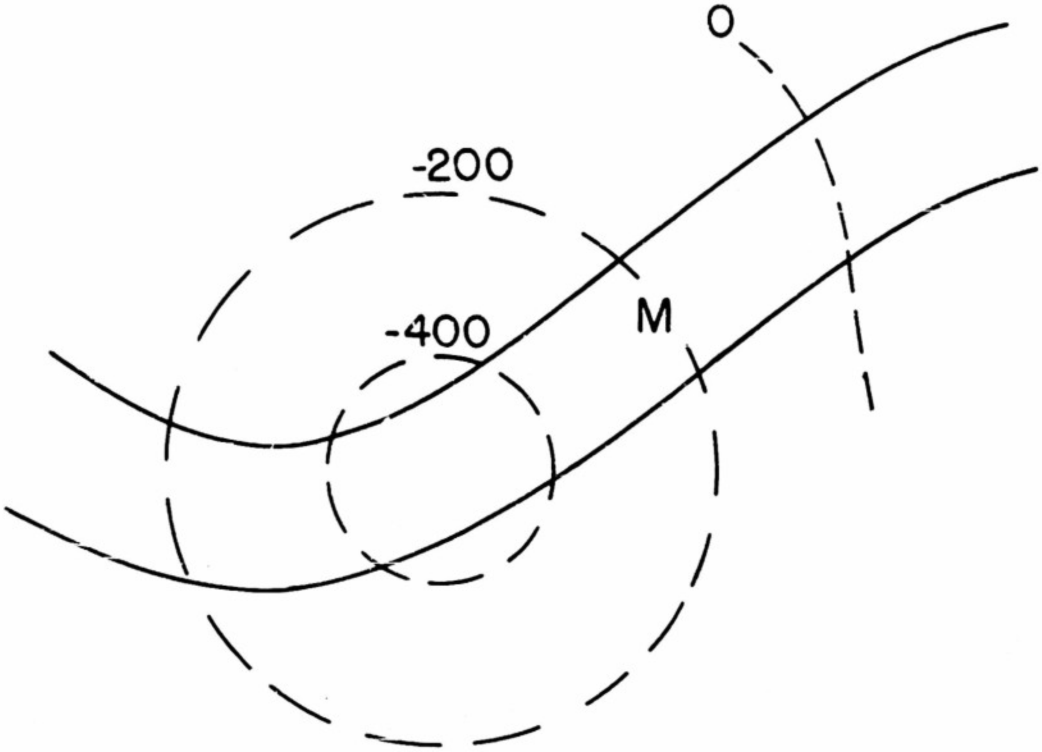


Fig. 1. An idealized contour pattern (solid lines) at 500 mb. The dashed lines are 12-hr height changes.

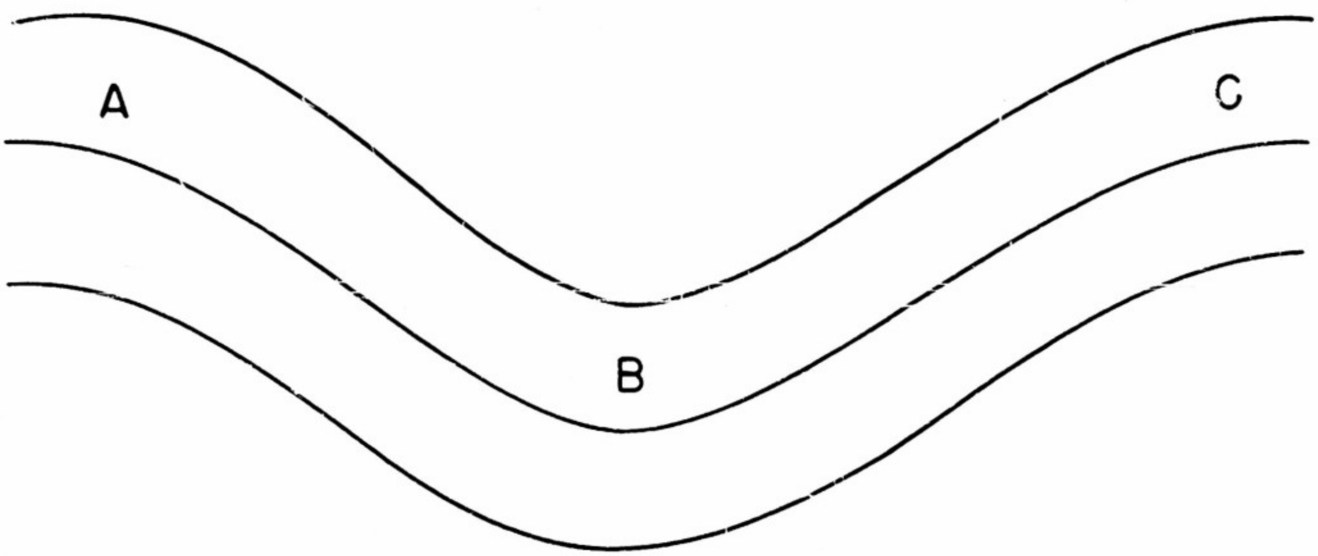


Fig. 2. An idealized trough-ridge pattern at 500 mb.

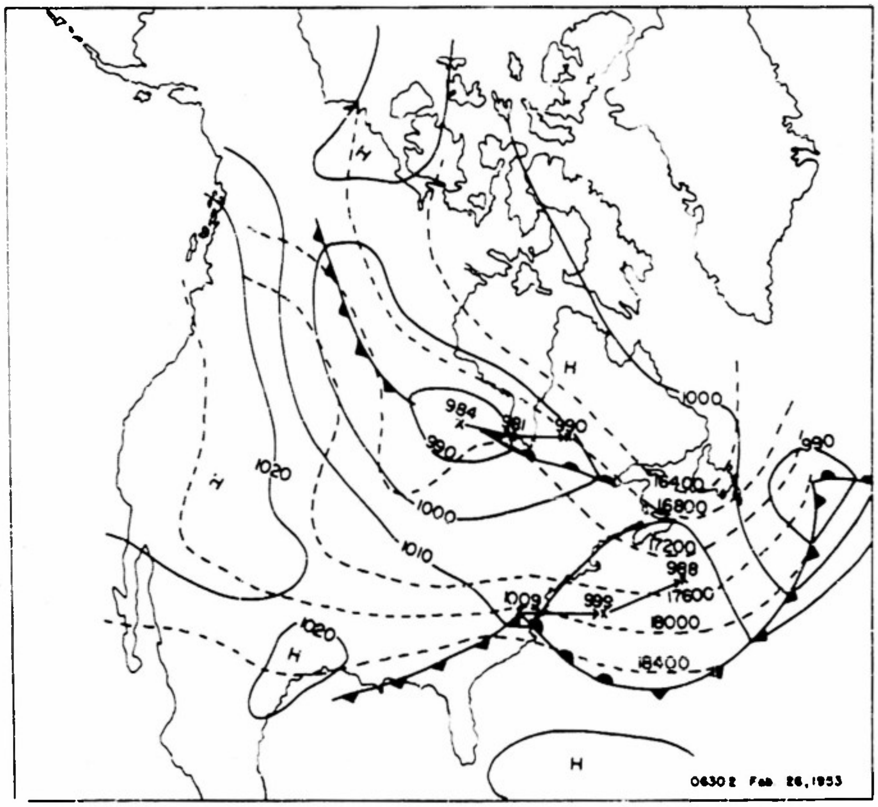
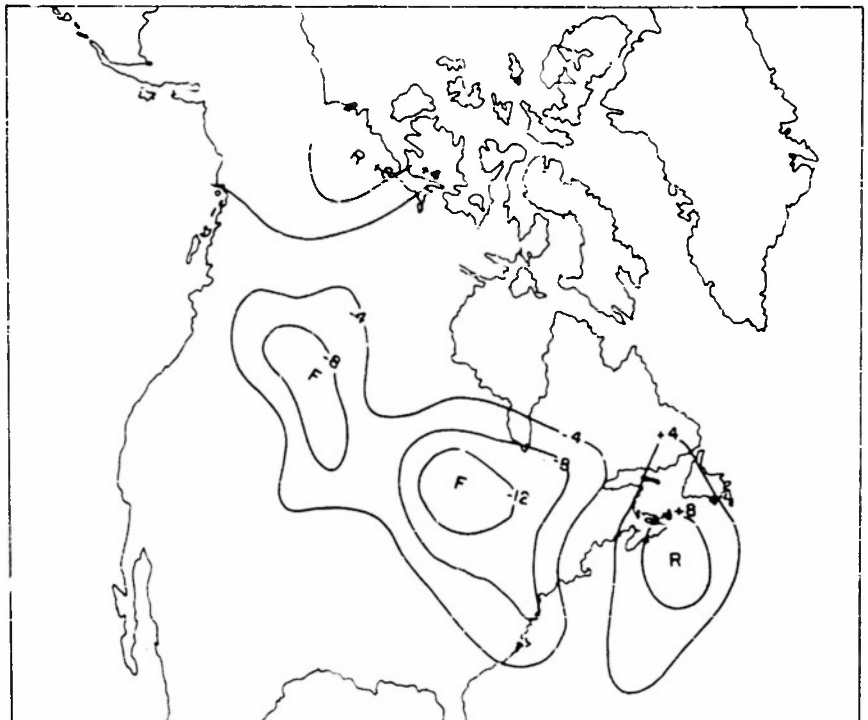
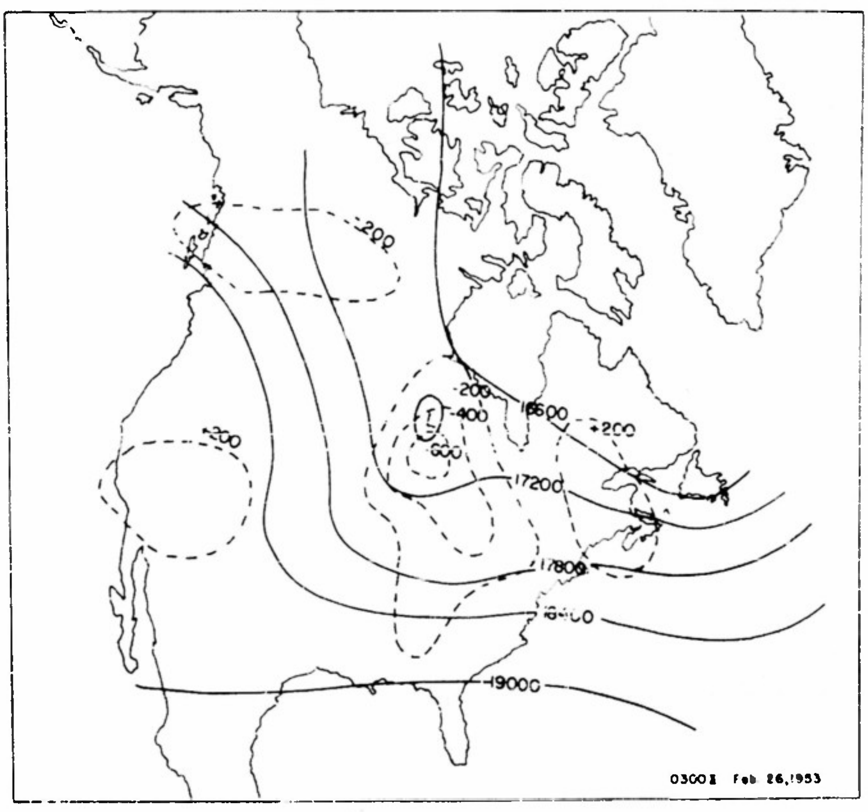


Fig. 3. Synoptic situation of Feb. 26, 1953. The dashed lines on the surface map are mean isotherms between 1000 mb and 500 mb. The x's are successive 12-hr positions of cyclone centers. The dashed lines on the 500 mb chart are 12-hr height changes.



12 hr pressure chge
1830Z Feb 25 - 0630Z Feb 26
1953



0300Z Feb 26, 1953

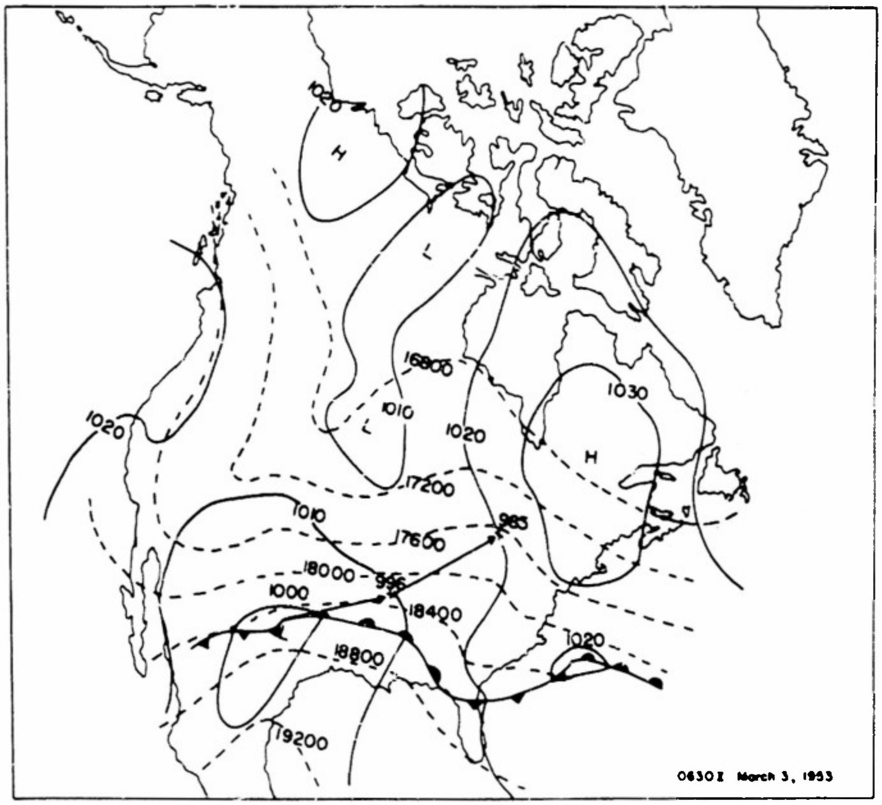
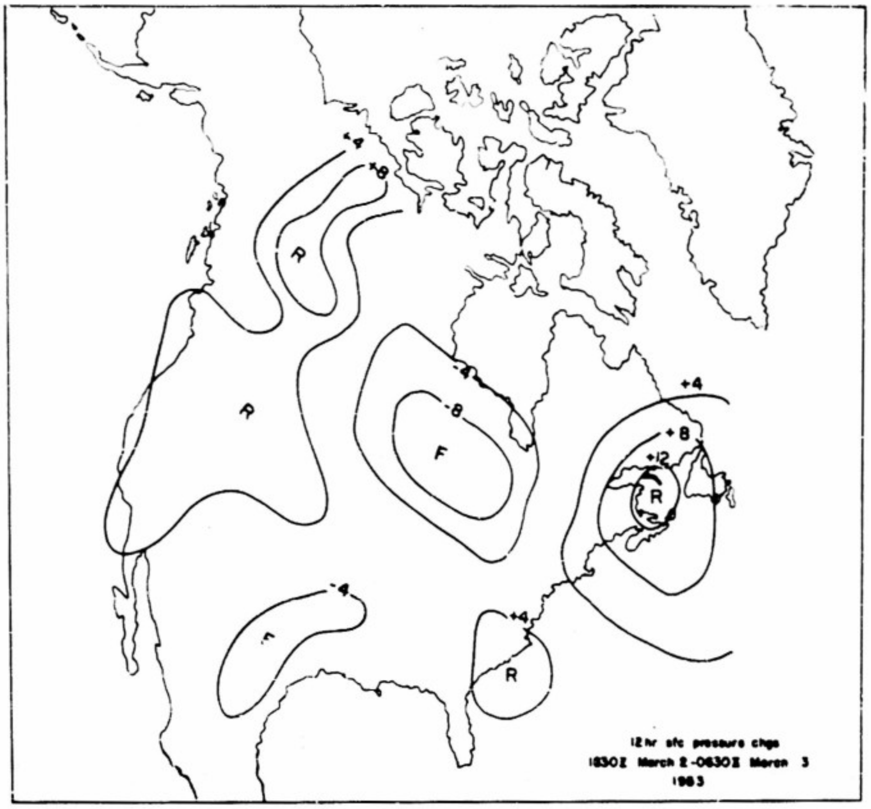
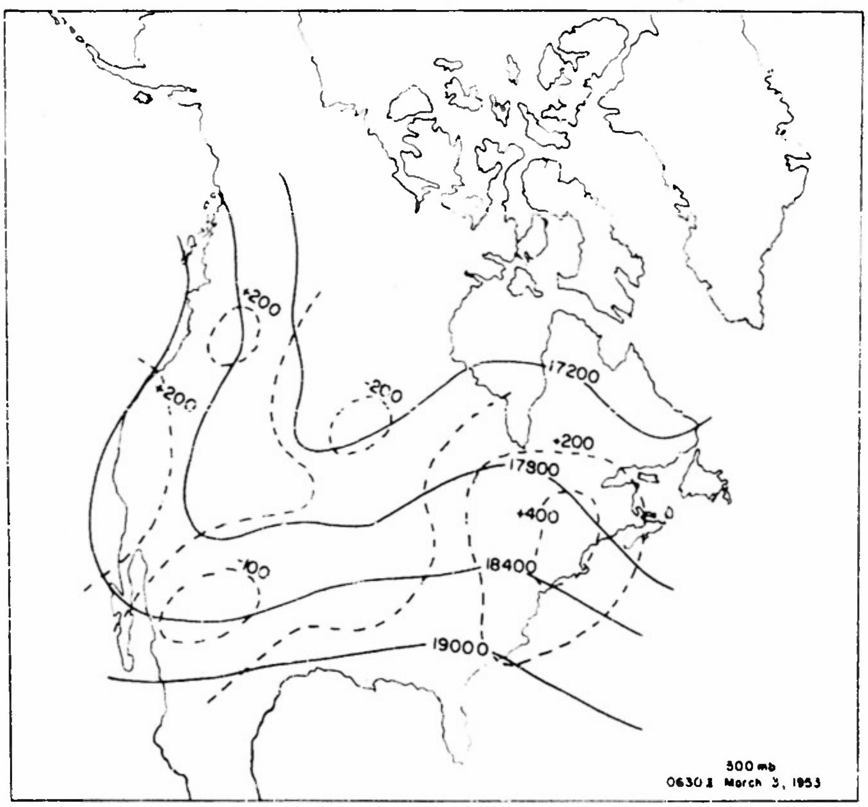


Fig. 4. Synoptic situation of March 3, 1953. The dashed lines on the surface map are mean isotherms, between 1000 mb and 500 mb. The x's are successive 12-hr positions of the cyclone center. The dashed lines on the 500 mb chart are 12-hr height changes.



12 hr sfc pressure chgs
1830Z March 2 - 0630Z March 3
1953



500 mb
0630Z March 3, 1953

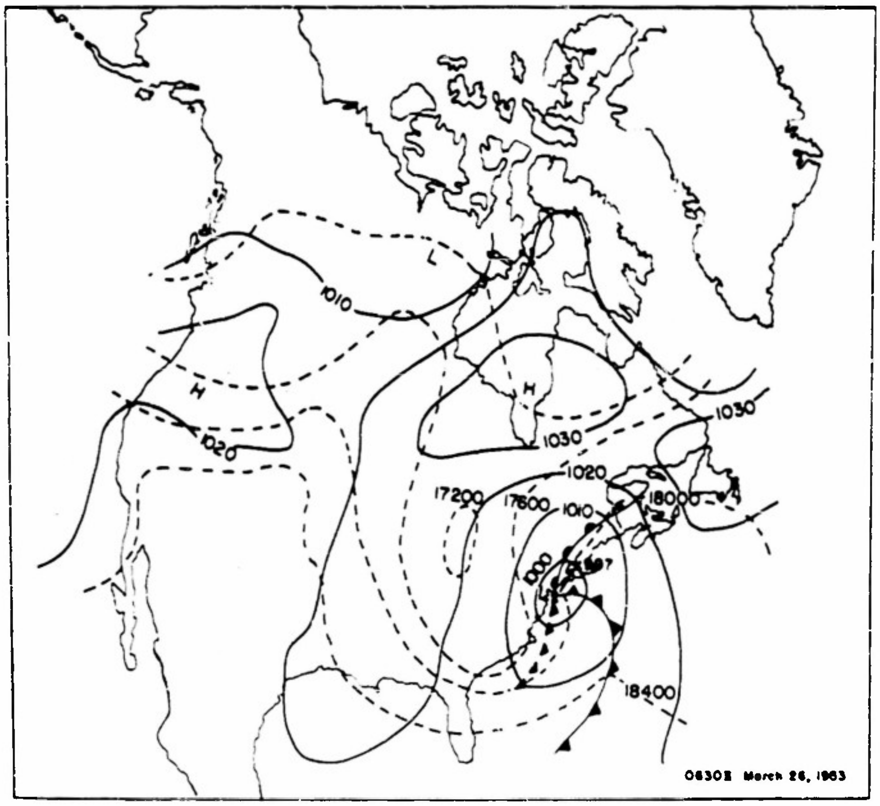
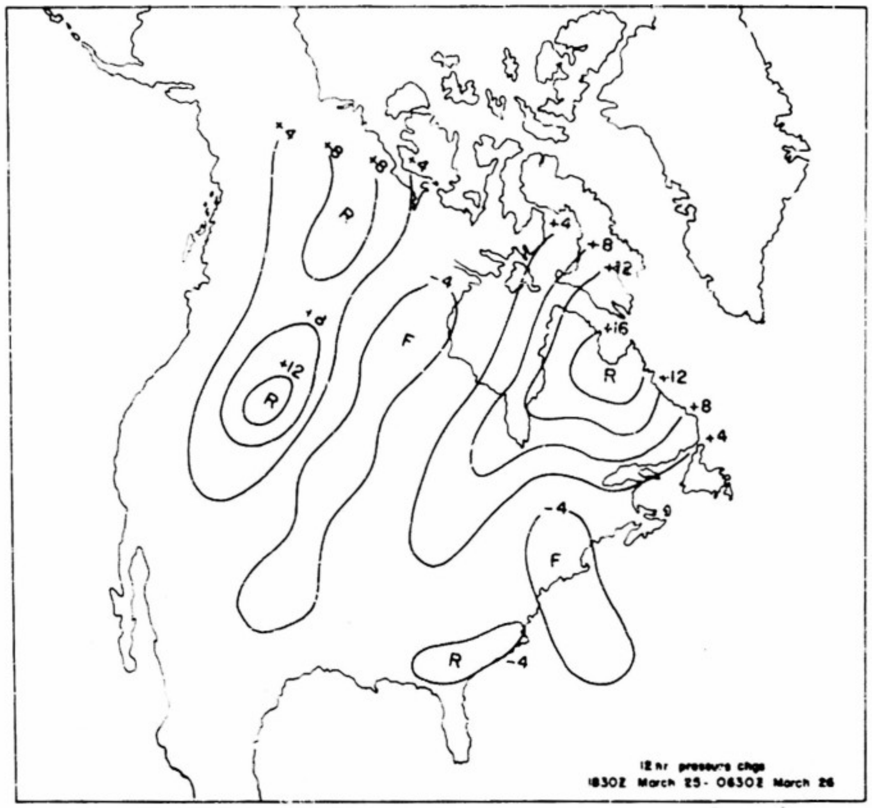
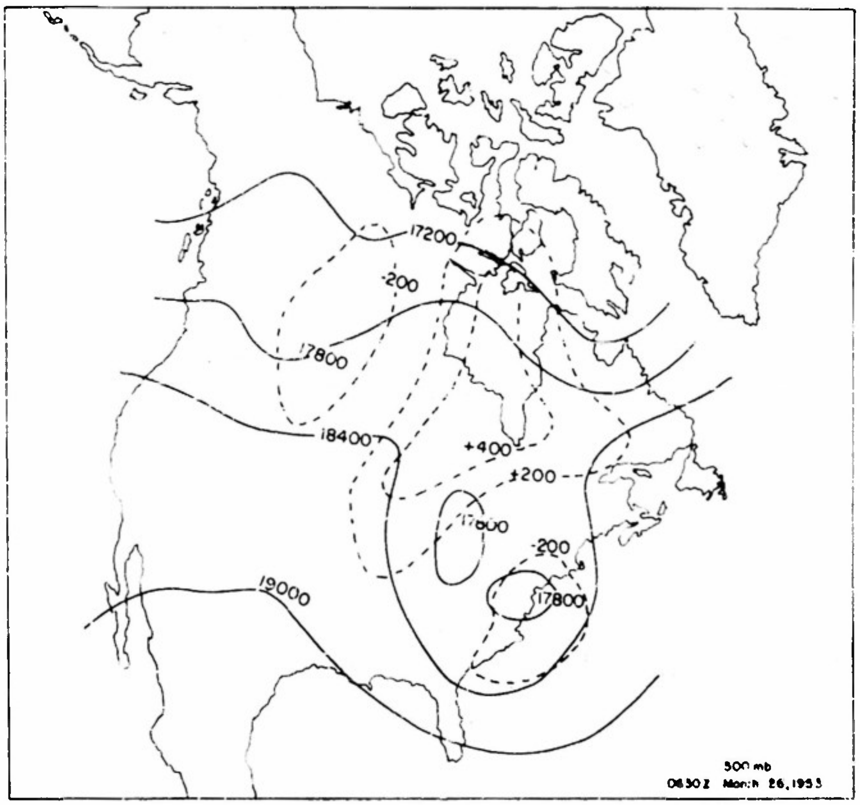


Fig. 5. Synoptic situation of March 26, 1953. The dashed lines on the surface map are mean isotherms between 1000 mb and 500 mb. The x denotes the 24-hr position of the cyclone center 24 hours later. The dashed lines on the 500 mb chart are 12-hr height changes.



12 hr pressure chgs
1830Z March 25 - 0630Z March 26



500 mb
0630Z March 26, 1953

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